APPLICATION OF A NEW CARBON-14 COUNTING TECHNIQUE TO EARTHQUAKE STUDIES

Allen B. Tucker

San Jose State University
Department of Physics
San Jose, California 95192

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1. INTRODUCTION

In the absence of written records that go back more than 150 years, the frequency of major earthquakes in the seismically active regions of the western United States can only be deduced from geologic evidence. Scarps along the Wasatch fault near Salt Lake City, Utah exhibit cumulative surface displacements as large as 10 meters in alluvial deposits that post-date the recession of Lake Bonneville 12,000 years ago; although no damaging earthquakes have occurred since the area was settled. Recent trenching studies by Swan et al. (1) have exposed ancient surface soil layers in which discontinuities reveal a sequence of significant surface faulting events. Radiocarbon dates of detrital charcoal from these deposits would be a record of earthquake recurrence intervals, vital data for contemporary earthquake hazards assessment. Most of the samples collected so far have been too small for conventional beta-decay counting. We report a successful radiocarbon assay by direct atom counting of four milligram-sized specimens from the Wasatch study.

Recently a new technique has been developed for measuring the relative amounts of specific isotopes in small samples. Basically it is high-energy mass spectrometry, utilizing the beam analyzing and particle identification tools of accelerator-based nuclear spectroscopy to count single atoms of selected isotopes (2,3).

2. MEASUREMENTS

The specimens consisted of small flecks of charcoal, presumably residue form forest fires, separated from soil samples taken from exploratory trenches on the Wasatch fault at Little Cottonwood Canyon, 20 km south of downtown Salt Lake City. Sputter source targets were prepared by dissolving approximately 4 mg of each sample in 50 mg of iron melted under vacuum. The resulting material would adhere to small tungsten blades which could be mounted in standard cones. Similar calibration targets were prepared from four charcoal specimens with known ages between 250 and 10,000 years, as determined by beta counting at radiocarbon labs at the University of Bern and the U. S. Geological Survey in Menlo Park.

The measurements were made with the EN tandem Van de Graaff accelerator at the ETH, Zürich. This facility is described in ref. 4. Mass selection of negative ions from a cesium sputter source was made by the injection magnet, the only element changed during the isotope counting cycle. Following acceleration, 22 MeV 3+ ions were selected by a 15° electrostatic analyzer. After precise collimation by a double set of slits defining beam direction as well as position, the monoenergetic ions were sorted in a magnetic spectrometer. Separate ports were provided for masses 12, 13, and 14; the field strength being held constant. The abundant isotopes were counted by collecting their currents in long Faraday cups. Atoms at the mass 14 port were detected and identified by a two-stage (dE/dx - E) gas filled ionization counter. The spectrum in Fig. 1 shows the separation of ^{14}C from background ^{14}N and ^{13}C.

The data were taken in a series of counts alternating between calibration and unknown samples. Each run consisted of a sequence of 20 computer controlled 3-minute counting cycles, 15 seconds at mass 12 and at mass 13 then 150 seconds at mass 14. Table 1 and Fig. 1 are typical data from one of the unknowns. The C13/C12 ratio was a monitor of system stability. The rms deviation of the C14/C12 ratios was compared to the fluctuation expected from the small number of total C14 counts; they were always consistent. Each sample was counted a minimum of three times during the 72 hours of the experiment. Repeated measurements agreed within the statistical accuracy of the C14 counts, approximately 10%.

Figure 2 displays the results. The four calibration points fall on a straight line with slope corresponding to a half-life of 5568 years, the vaule used in decay dating. All the geologic specimens produced countable beams. Unknown to us during the experiment, the geologists suspected sample WCC-4 to be modern material from a burned root. The data confirm this. Three specimens were ancient material, having C14/C12 ratios corresponding to ages of 7800, 8800, and 9000 years with counting statistical uncertainties of ± 600 years. These ages are consistent with the geologic evidence that this material was deposited after the recession of Lake Bonneville about 12,000 years ago. A larger charcoal sample from a nearby site had an age, as determined by beta counting, of approximately 5,600 years. Unfortunately, strata in the formation from which this sample was taken could not be correlated with those at Little Cottonwood Canyon, but the similarity of the ages of samples from the two sites was expected.

3. FUTURE APPLICATIONS

Atom counting offers the field geologist two advantages over the standard beta counting technique. First is the ability to analyze very small samples, a few milligrams compared to the grams required by commercial radiocarbon labs. If a fleck of charcoal can be seen, it can be counted. This capacity should lead to new data from strata in which no large specimens exist.

Second is the potential for prompt results. Decay counting takes weeks or, for small samples, months. The atom counting facilities being developed throughout the world will be able to date samples within days. Data can be available while a trench is still open and the geologists are still in the field. Preliminary judgements can be tested and revised while additional samples are still easily available.

We anticipate that this new technique will produce a large body of data on earthquake recurrence intervals in the western United States.

Table 1. Typical raw data for sample WCC-2.

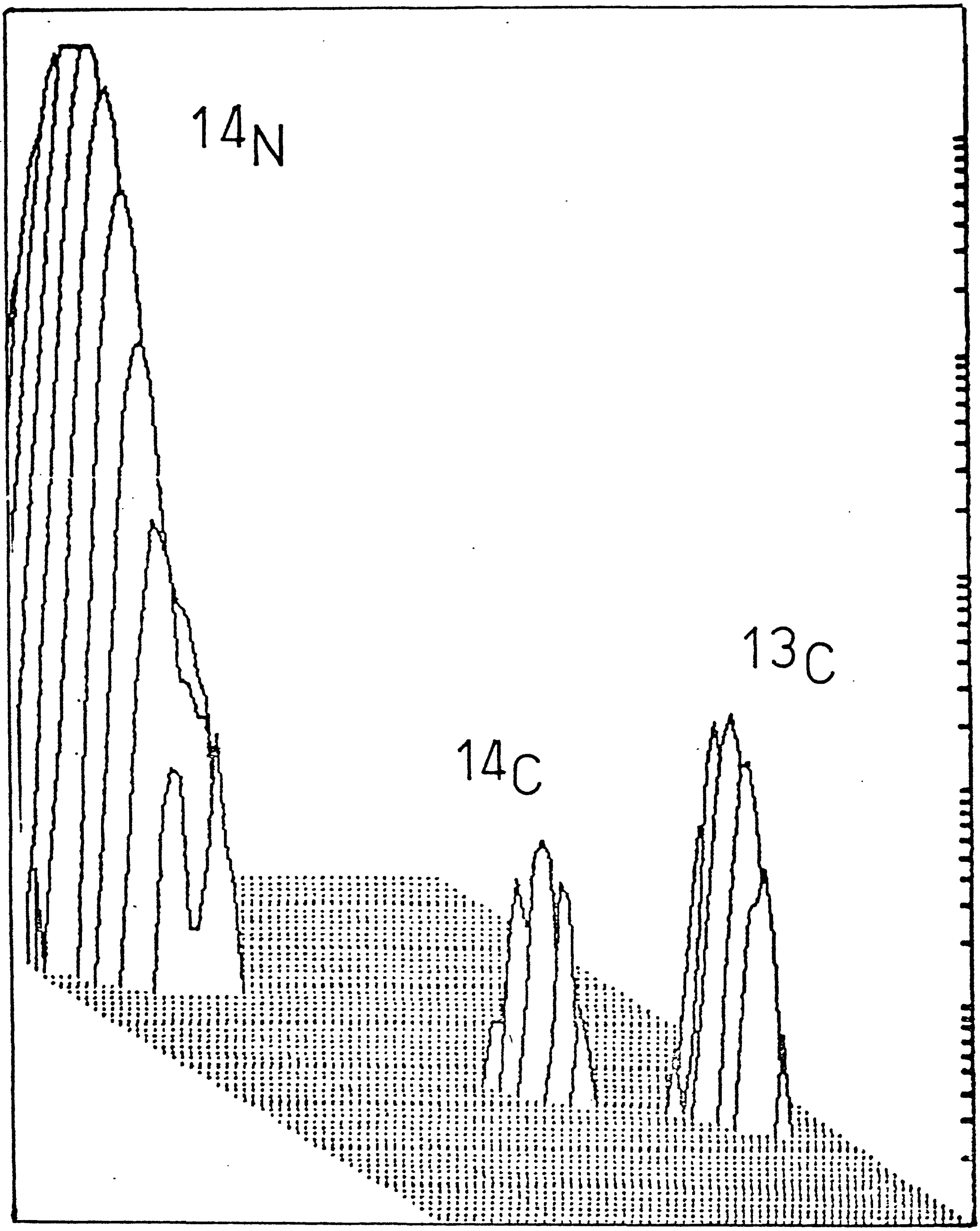
Cycle	C14[a]	C13[b]	C12[b]	C13/C12[c]	C14/C12[d]
1	7	3884	1221	1.060	0.382
2	5	4059	1258	1.075	0.265
3	7	4150	1304	1.061	0.358
4	5	4285	1355	1.054	0.246
5	5	4418	1347	1.093	0.248
6	2	4381	1284	1.137	0.104
7	11	4257	1321	1.074	0.555
8	8	4553	1295	1.172	0.412
9	3	4425	1409	1.047	0.142
10	5	4581	1420	1.075	0.235
11	10	4549	1411	1.075	0.473
12	8	4428	1336	1.105	0.399
13	8	4548	1431	1.059	0.373
14	3	4588	1443	1.060	0.139
15	5	4592	1436	1.066	0.232
16	4	4625	1415	1.089	0.189
17	6	4520	1412	1.067	0.283
18	4	4669	1466	1.062	0.182
19	7	4676	1465	1.064	0.319
20	8	4709	1476	1.063	0.361
Totals	121			1.077	0.293
	($\pm$9%)			($\pm$0.6%)[e]	($\pm$9%)[e]

a) Counts.
b) Integrated current, different normalizations for C12 and C13.
c) Percent.
d) Normalized to 1.0 for the expected ratio from contemporary material.
e) Standard deviations.

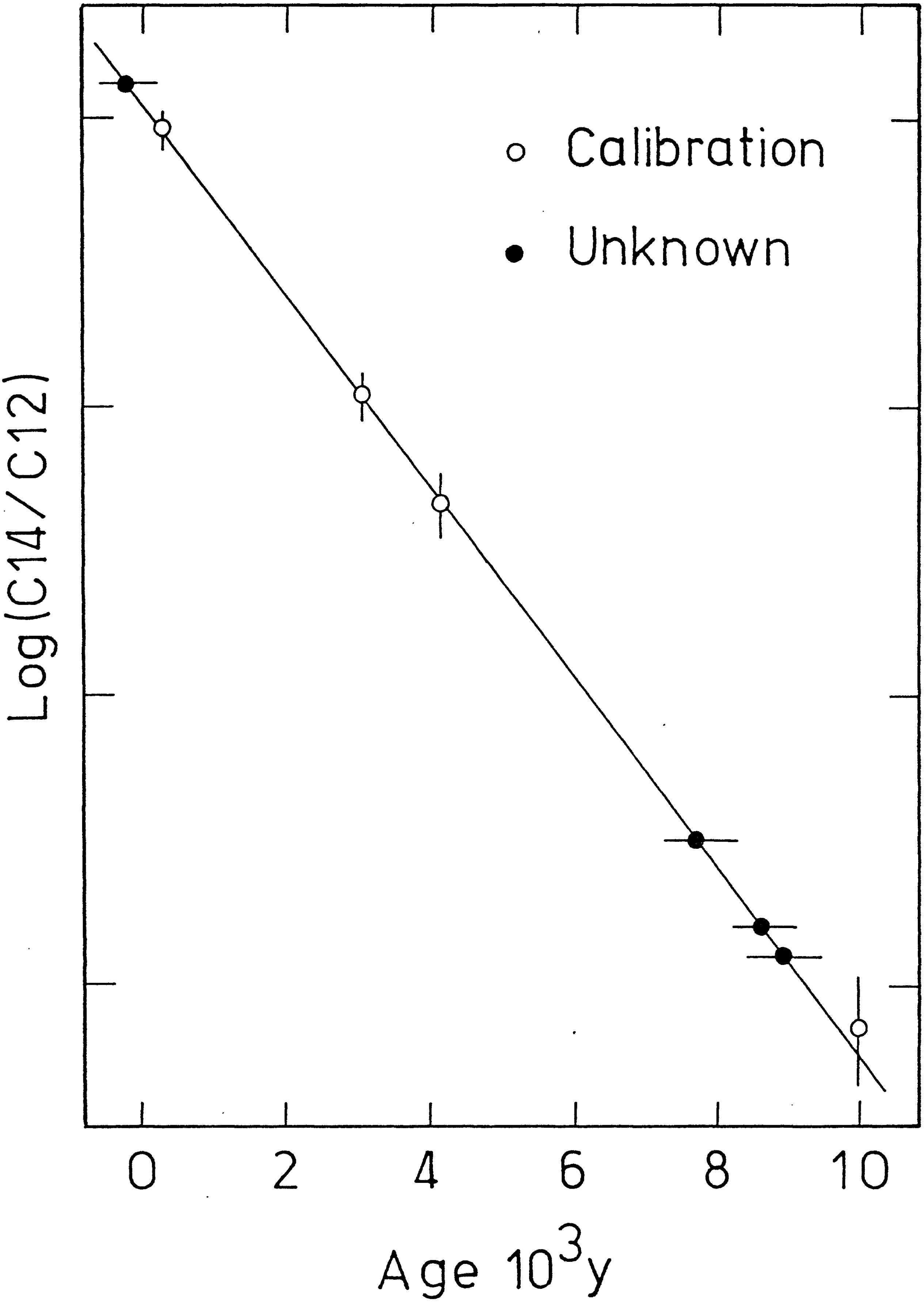
Figure Captions

Figure 1. Particle identification spectrum, dE/dX vs E.

Figure 2. Results. Open circles are calibration points fit with a half life of 5568 years; solid circles are data from the unknowns.



^{14}N
^{14}C
^{13}C


Calibration
Unknown
Log(C14/C12)
0
2
4
6
8
10
Age 10³y

References

1. F. Swan III, D. Schwartz, and Lloyd Cluff, Bull. Seis. Soc. Am. 70, #5 (1980).

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4. M. Suter, R. Balzer, G. Bonani, W. Wolfli, J. Beer, H. Oeschger, and B. Stauffer, Proceedings of the Sixth Conference on the Applications of Accelerators in Research and Industry, Denton, Texas, November 1980, IEEE Transactions on Nuclear Science, Vol. NS-28 No. 2, p 1475, April 1981.